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(71) Applicant (*for all designated States except US*): ASEA BROWN BOVERI AB [SE/SE]; S-721 83 Västerås (SE).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): BERGGREN, Sören [SE/SE]; Vetterstorpsgatan 30, S-724 62 Västerås (SE). LEIJON, Mats [SE/SE]; Hyvlarvägen 5, S-723 35 Västerås (SE).

(74) Agent: EMTEDAL, Artur; L. A. Groth & Co. KB, P.O. Box 6107, S-102 32 Stockholm (SE).

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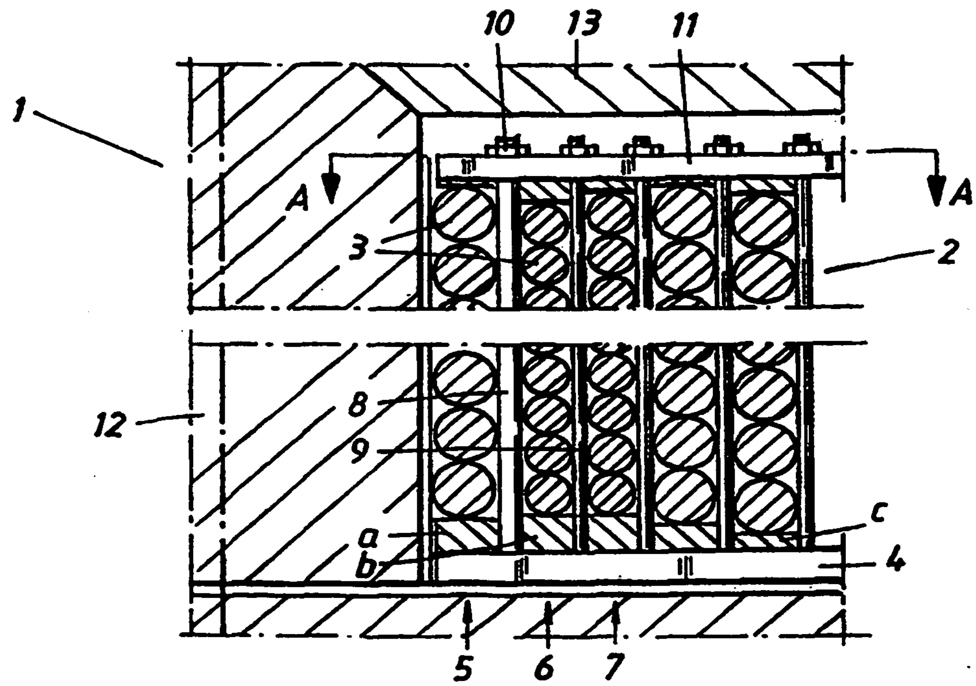
(54) Title: A MECHANICALLY SUPPORTED WINDING

(57) Abstract

A power transformer (1) or a reactor comprising a winding (3) formed as a winding coil (2) having concentrically arranged winding turns, wherein at least one winding turn is formed by a high voltage cable (111) provided with an outer semiconducting layer (115) and that the winding (3) is provided with winding separating spacers (8, 9), arranged axially between each winding turn, arranged to hold the winding (3) axially together.



A mechanically supported winding.

Technical field

The present invention relates to a winding of an air cooled conductor wound power transformer or a winding of a reactor the winding of which being provided with spacers between the conductor windings to enable air cooling and earthing in a winding structure held mechanically together.

Background art

Today's power transformers are normally oil cooled. The transformers are provided with a core consisting of a number of core legs connected by yokes and windings constituting coils (primary, secondary, regulated) which are immersed in a sealed tank filled with oil. The heat, generated in the coils and core, is removed by oil circulating internally through the coil and core and released in to the surrounding air via the walls of the vessel. Oil circulation may either be forced by pumping the oil around or it may be natural due to temperature differences in the oil. The circulating oil is cooled externally through air- or water cooling devices. External air cooling of oil may be forced and/or effected through natural convection. The oil has an insulating function besides its role as conveyer of heat in oil cooled transformers for high voltage.

Dry transformers are normally air cooled. They are normally cooled by natural convection as today's dry transformers are used at low power loading. The present technology related to axial cooling ducts, produced by means of a corrugated winding, is disclosed in GB 1.147.049, axial ducts for cooling of windings embedded in cast resin is disclosed in EP 83107410.9 or the use of cross flow fans at peak load is disclosed in SE 7303919-0.

Furthermore, conventional power transformers are provided with special rings so that the stability of the windings is ensured against short circuit forces. The windings are mounted as a unit on the core. A series of plates is thereafter mounted in series which is tightened against a barrier cylinder. The whole installation is mounted in line on a lower spacer ring. A compression ring which prestresses the windings is located between the yoke of the core and the windings. The short circuit forces must consequently be absorbed by the yoke of the iron core by means of its clamps which keep the lamination in place.

There is no iron core in the event of windings being used to compensate for reactive power in a reactor. The windings in this case are formed solely of a coil.

A conductor is known through US 5 036 165, in which the insulation is provided with an inner and an outer layer of semiconducting pyrolized glassfiber. It is also known to provide conductors in a dynamo-electric machine with such an insulation, as described in US 5 066 881 for instance, where a semiconducting pyrolized glassfiber layer is in contact with the two parallel rods forming the conductor, and the insulation in the stator slots is surrounded by an outer layer of semiconducting pyrolized glassfiber. The pyrolized glassfiber material is described as suitable since it retains its resistivity even after the impregnation treatment.

Object of the invention

The object of the invention is to produce a new type of winding in a power transformer or a reactor comprising a high voltage cable having an outer semiconducting layer. The winding is provided with spacers, which are arranged to produce cooling ducts between concentric winding turns, as well as constituting means for axially prestressing the winding. The problem of short circuit forces in the winding is hereby solved so that the clamps, previously absorbing forces

in for example transformers, may be produced lighter and smaller in size. This results in reduced eddy currents in the clamps hereby reducing the total eddy current losses.

The windings are hereby in the form of a mechanically compact and integral winding unit which may absorb stresses, such as short circuit forces, without transmitting the forces to the iron core in a transformer.

A further object of the invention is to provide axial cylindrically formed ducts between each winding turn in the windings wherein the cooling agent is correctly distributed in order to meet the cooling requirements of the windings. The cylindrical ducts are created by spacers which are inserted during winding of the coil. The cooling flow is produced by fans and the spacers are dimensioned such to produce the flow in the ducts which meets the individual cooling requirements of the windings.

Another advantage of the present transformer design is that the windings are mounted on cable drums in the cable factory, prior to being installed around the iron core on site which is a great improvement in the production technique of these types of transformers.

Summary of the invention

The present invention relates to a winding of a power transformer or a reactor. The winding comprises a high voltage cable which is wound around a transformer core of the transformer design. The winding is provided with a plurality of spacers extending axially along the length of the winding, separating each cable turn of the winding radially in order to create among other things axial cylindrical cooling ducts.

According to an embodiment of the invention the winding is thus arranged with axial cylindrical cooling ducts

between each winding turn, arranged on the outside, which ducts are created by spacers during winding of the core.

According to the embodiment, the spacers are also arranged to axially clamp the winding together to form an integral winding unit which among other things may absorb mechanical short circuit forces.

Furthermore the spacer is arranged with an elastic layer in order to absorb vibrations which may arise in the winding.

In a power transformer according to the invention the windings are composed of cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the device according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of a XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

Windings in the present invention are constructed to retain their properties even when they are bent and when they are subjected to thermal stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive

here, particularly their elasticity and relative coefficients of thermal expansion. In a XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1} - 10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating lay may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene (PMP), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber, butyl graft polyethylene, ethylene-butyl-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers. Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damage appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them. There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Brief description of the drawings

The invention will now be described in more detail with particular reference to the accompanying drawings in which:

Figure 1 shows schematically an axial view of the centre of the winding according to the present invention;

Figure 2 shows a view A-A according to Figure 1 of a winding coil provided with spacers according to the invention;

Figure 3a shows a partial view through an upper end plate according to the present invention;

Figure 3b shows a partial view through a lower end plate according to the present invention;

Figure 4 shows a view through a high voltage cable according to the present invention.

Description of the invention

Figure 1 shows a cross-section through a power transformer 1 provided with a winding coil 2 with windings 3 arranged in spiral form beginning with a lower end plate 4 and wound upwards. The windings may but need not be connected to each other. Different windings with different cable diameters are part of the embodiment shown in the Figure. As shown in the Figure, due to different cable diameters in different cable turns , each winding is provided with axial spacers a, b, c to fit into the axial position of each winding of the coil. A plurality of spacers 8, 9 is inserted between each winding turn 5, 6, 7. A first spacer 8 is hereby inserted between a first winding turn 5 and a second winding turn 6 arranged concentrically . A second spacer 9 is inserted between the second winding turn 6 and a third likewise concentric winding turn 7, and so forth. Each spacer 8, 9 of the winding coil 2 is clamped to the lower endplate 4 and tightened by clamping means 10 against an upper end plate 11.

As shown in Figure 1 the first spacer 8 is thicker than for example the second producing a broader duct between the winding turns. The winding coil constitutes a self containing part, independent of the iron core, which does not need to be supported against the iron core in order to compensate for all of the occurring short circuit forces. The winding structure may but need not be in contact with the iron core at the so called window. The winding coil 2 surrounds a leg 12 of the iron core which leg, at its lower and upper end, is connected to a yoke 13 so as to be in contact with another leg (not shown). Spacers 8, 9 are either cylindrical or rectangular in cross-section and are provided at least at the one end with a clamping means in the form of a nut with a screw or wedge arrangement. As shown in Figure 2 the spacers 8, 9 are placed radially outwards from the leg 12 of the iron core with the end plates 4, 11 in a "spoke" formation. There are 12 end plates 11 distributed around the whole winding coil 2 in a preferred embodiment, the number of endplates however varying between eight and sixteen depending on the size of the winding. Five spacers are placed radially through each "spoke" of a winding coil of the present type. Spacers 8, 9 produce additionally axial cylindrical cooling ducts 13, 14 between each radially positioned winding 5, 6, 7. The winding turns are air cooled in that air is pressed through the ducts by fans (not shown). Spacers 8, 9 are placed throughout the winding coil 2, and are axially longitudinal. The spacers are inserted between the winding turns during winding of the coil.

Thus, each winding coil is surrounded by a cooling duct wherein cool air is arranged to flow. Cooling requirements differ between windings which implies that there are different cooling flows in the concentric ducts. In order to achieve the correct cooling of the ducts, as indicated above, the latter are arranged in radial direction according to their different dimensions.

The first spacer 8 is of metal or reinforced plastic, coated with a rubber layer 16, which functions as a

spring in order to dampen vibrations in the winding during operation. The clamping means is designed in one embodiment as a wedge and designed in a second embodiment as a screw-bolt mechanism. The winding unit may hereby be clamped so that the winding functions mechanically as a separate unit. The pressure exerted during clamping is sufficient to keep the windings in place and not higher than what the XLPE-insulation of the cable is able to withstand. In this embodiment the transformer unit is furthermore anchored to the iron core in a suitable manner.

Figure 3a shows the upper end plate 11 which is provided with openings 16, a number of which corresponds to the number of spacers 8. Spacers 8 extend through the openings 16, the former arranged to be axially tightened against the end plate 11 by means of a tensional withstanding nut 18. In the case of the spacer being electrically conducting, its end is connected to an earthing means 20. Additionally, Figure 3a shows that the core 22 of the spacer 8 is connected at its upper end to a welded upper bolt 31 which is provided with a screw 32 in order to be tightened by a nut 18 against the upper endplate 11.

The core of the spacer 8 is connected at its lower end 33, see Figure 3b, to a welded lower bolt 34, which in likewise manner to the above is provided with a screw 35 for a lower nut 36, for it to be tightened against the lower end plate 4. In the Figure the winding turns are designated by the numerals 1-8 whereby the innermost winding turn is designated by the numeral 1 and the outermost winding turn is designated by the numeral 8. As shown in the Figure each spacer 8 is provided with a flexible damping means 40 preferably of rubber. The thickness of the damping means 40 is adjusted to the distance between the winding turns depending on the fact that different winding turns may be formed of cables with differing diameter. The winding unit is furthermore locked to the core of the transformer by means of a core distancer 42 being screwed to the lower bolt 34 which in its turn is

secured by screw joints to the transformer core via a base plate 44.

Figure 4 shows a view through a high voltage cable 111 to be used in a winding according to the present invention. The high voltage cable 11 comprises a number of strands 112 with circular cross-section of for example copper (Cu). These strands 112 are arranged in the centre of the high voltage cable 111. Around the strands 112 there is arranged a first semiconducting layer 113. Around the first semiconducting layer 113 there is arranged an insulating layer 114, of for example XLPE-insulation. Around the insulating layer 114 there is arranged a second semiconducting layer 115. The concept of a high voltage cable in the present application does not comprise thus the outer shielding screen that normally surrounds such a cable for power distribution. The high voltage cable has a diameter in the interval of 20 - 250 mm and a conductor area in the interval of 40 - 3000 mm^2.

The invention is applicable to both a power transformer and a reactor.

CLAIMS

1. A power transformer (1) or a reactor comprising a winding (3) formed as a winding coil (2) having concentrically arranged winding turns, characterized in that at least one winding turn is formed by a high voltage cable (111) provided with an outer semiconducting layer (115) and that the winding (3) is provided with winding separating spacers (8, 9), arranged axially between each winding turn, arranged to hold the winding (3) axially together.

2. A device according to claim 1, characterized in that the spacers (8, 9) are arranged to cooperate with support means (4, 11) extending radially on both sides of the winding coil (2) in order to form a mechanical winding structure having concentrically arranged windings in a cage like construction.

3. A device according to claim 2, characterized in that a supporting means (4, 11) is formed as an upper end plate (11) provided with openings (16) through which spacers (8, 9) are extended whereby the spacers (8, 9) are arranged to be axially tightened against the upper end plate (11).

4. A device according to claim 3, characterized in that the upper end plate (11) extends radially, from the innermost winding turn (5) to the outermost winding turn, over the entire winding coil.

5. A device according to claim 4, characterized in that a number of supporting means (4, 11) are arranged radially, over at least one entire side of the winding coil (2), forming a spoke formed support side.

6. A device according to any one of claims 2 - 5, characterized in that one supporting means (4, 11) is formed as a lower end plate (4) to which the spacers (8, 9) are clamped or that the lower end plate (4) is provided with

openings (16) through which the spacers (8, 9) extend whereby the spacers are arranged to be axially tightened against the upper end plate (11).

7. A device according to claim 6, characterized in that a plurality of lower endplates (4) are arranged radially, on the entire side of the winding coil (2) forming a spoke formed lower support side.

8. A device according to claim 7, characterized in that the outer semiconducting layer (115) is earthed.

9. A device as claimed in any of claims 1-8, characterized in that the winding is flexible and composed of an electrically conducting core surrounded by an inner semiconducting layer (113), an insulating layer (114) of solid material surrounding the inner semiconducting layer (113), and an outer semiconducting layer (115) surrounding the insulating layer (114), said layers (113,114,115) being adhered to each other.

10. A device as claimed in any of claims 1-9, characterized in that said layers (113,114,115) are of materials having such elasticity and such coefficient of thermal expansion that the changes in volume in the layers (113,114,115) caused by temperature fluctuations during operation are absorbed by the elasticity of the material, the layers (113,114,115) thus retaining their adhesion to each other upon the temperature fluctuations that occur during operation.

11. A device as claimed in any of claims 1-10, characterized in that the material in said layers (113,114,115) has high elasticity, preferably with a modulus of elasticity less than 500 MPa, preferably less than 200 MPa.

12. A device as claimed in any of claims 1-11, characterized in that the coefficients of thermal

expansion for the materials in said layers (113,114,115) are substantially the same.

13. A device as claimed in any of claims 1-12, characterized in that the adhesion between layers (113,114,115) is of at least the same magnitude as in the weakest of the materials.

14. A device as claimed in any of claims 1-13, characterized in that each of the semiconducting layers (113,115) essentially constitutes one equipotential surface.

Fig. 1

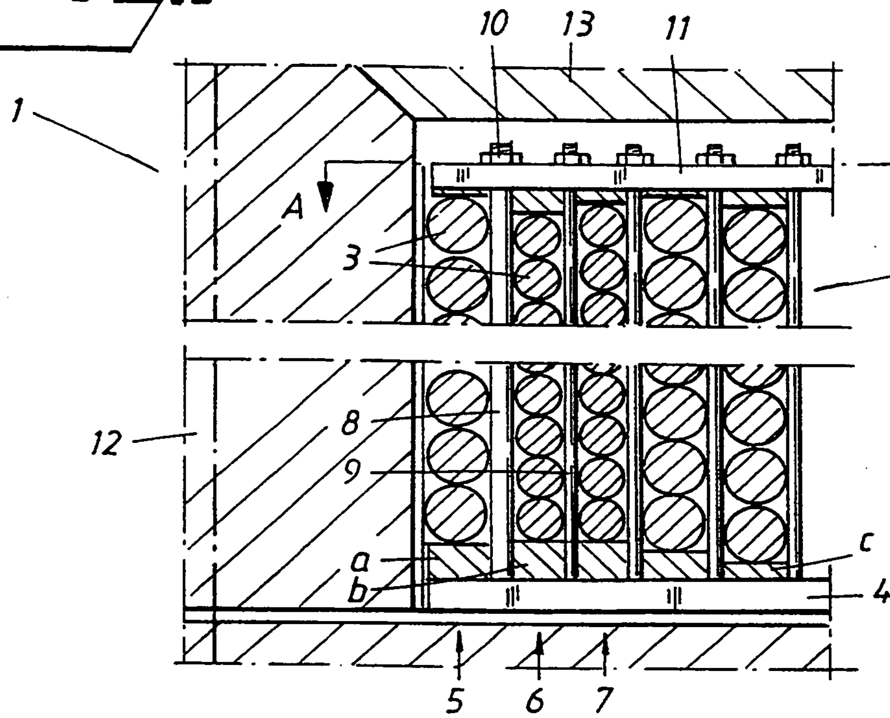
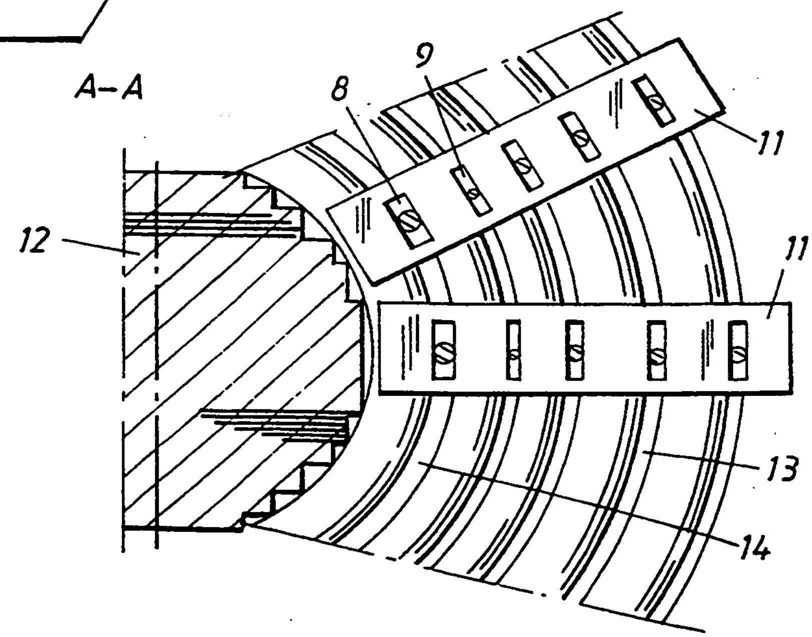


Fig. 2

A–A



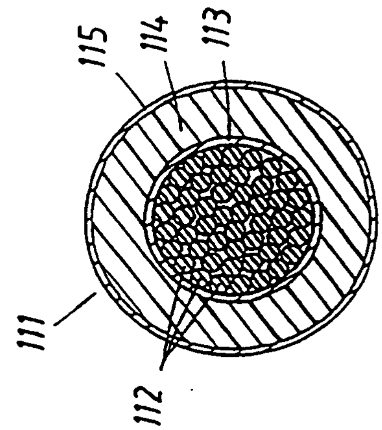


Fig. 4

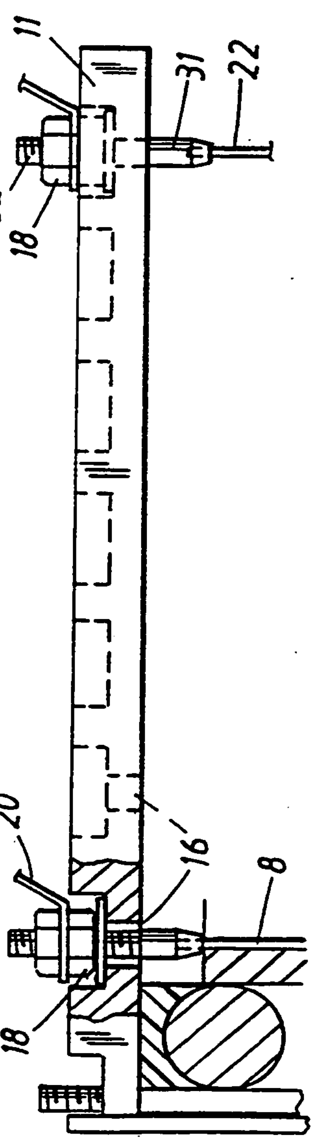


Fig. 3a

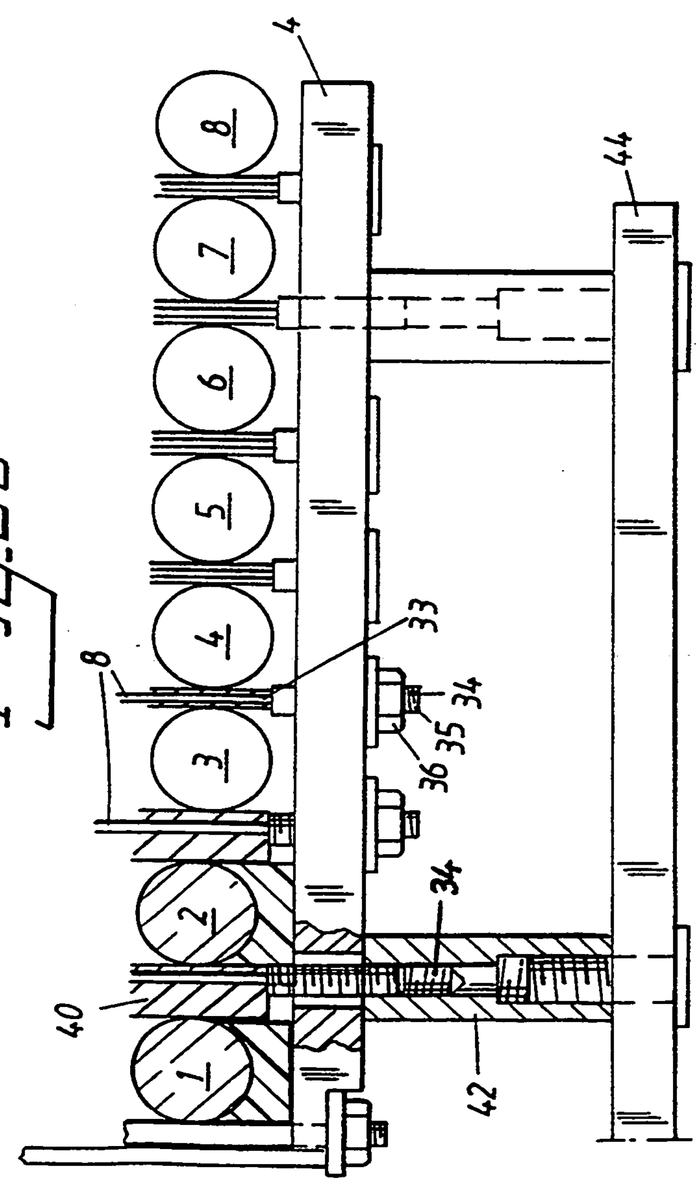


Fig. 3b

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00160

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01F 27/30
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EDOC, WPIL, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 1747507 A (R.B. GEORGE), 18 February 1930 (18.02.30), see the whole document --	1
A	US 5036165 A (RICHARD K. ELTON ET AL), 30 July 1991 (30.07.91), abstract -- --------	1

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 June 1998	17 -06- 1998
Name and mailing address of the ISA/ Swedish Patent Offic Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Magnus Westöö Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

29/04/98

International application No.
PCT/SE 98/00160

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 1747507 A	18/02/30	NONE	
US 5036165 A	30/07/91	US 5066881 A	19/11/91
		US 5067046 A	19/11/91
		CA 1245270 A	22/11/88
		US 4853565 A	01/08/89